

# A GRID CONNECTED SOLAR PHOTOVOLTAIC INVERTER WITHOUT AN OUTPUT FILTER USING HARMONIC MINIMIZING TECHNIQUE

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## ABSTRACT

This paper presents a sine-wave modulation technique to achieve low total harmonic distortion (THD) of a buck–boost converter connected to a changing polarity inverter. A PWM technique is used to achieve the low total harmonic distortion (THD) at the output of inverter during the construction of pulses to the converter switches. By using PWM modulation techniques we can minimize harmonics generated by the PWM technique itself. First, we present converter topology characteristics with PWM techniques. Then we describe how a suggested modulation minimizes harmonic generated by switching operation, the inductive nature of the DC source and external point at which the converter is connected. As compared with the previously modulation technique, a suggested modulation achieves the THD is less than 6%. Then, we describe how the suggested modulation improves the harmonic content of the output in comparison to the previously used technique, whether harmonics are caused by the inductive nature of the source (e.g., domestic wind turbine) or they are created from external sources at the point the converter is connected (e.g., grid). Simulation results the ability of the method to drastically reduce THD, the output complies with the 5% limit without the use of filters.

**Keyword:** - Buck-Boost converter, AC to DC converter, PV, Inverter, Total harmonic distortion

## 1. INTRODUCTION

The rapid development of renewable generation boosted the need for efficient, cheap, and robust converters that would interface them to the grid, without compromising the quality of supply for the end user. Most renewable provide a dc source of electric power, thus proper interfacing to the grid requires at least an inverter. Often, due to the low voltage acquired from sources such as domestic wind turbines, solar arrays or fuel cells, a boost converter or/and a transformer (if isolation is required) is added at the dc or ac side, respectively, in order to boost the voltage to the appropriate level. The most common type of commercial inverter used for this kind of applications is a variation of sinusoidal pulse width modulation full-bridge inverter. The simplicity of the design provides robust operation and simple control, but the harmonic content of the output requires a low-pass filter to comply with the standards.

Two disadvantages of this application are the increased size and cost due to the filter and the losses of the semiconducting switches performing the inverting operation at the inverter bridge (four) and the boost converter (one), usually, at a non acoustic frequency. Several PWM methods have been developed in order to reduce the harmonic content. Selective harmonic elimination solves the transcendental equations characterizing harmonics, so that appropriate switching angles are computed for the elimination of specific harmonics at the output [1]–[3].

Theoretically, these methods can provide a satisfying harmonic content. However, the solution of these equations is computationally intensive, thus, quite difficult to be done online. In small-scale applications, where powerful digital signal processors (DSPs) are not currently an option due to their higher cost, either switching angles are calculated offline [4]–[8], or the equations are liberalized before they are solved [9], [10], or an approximate solution is sought where the topology permits it [11]. Other methods include modification of the carrier signal [12]–[14] or the

reference sine wave [15], [16]. All of them, though, are open-loop control schemes, which assume a known and perfectly constant dc source (i.e., harmonics induced to the grid by an inductive source are ignored) and ignore the existing harmonic content of the grid voltage or the distortion caused by the load. In simple terms, they aim to reduce the harmonics created by the PWM itself, rather than improve the harmonic content at the terminal bus, which is affected by the PWM only partially.

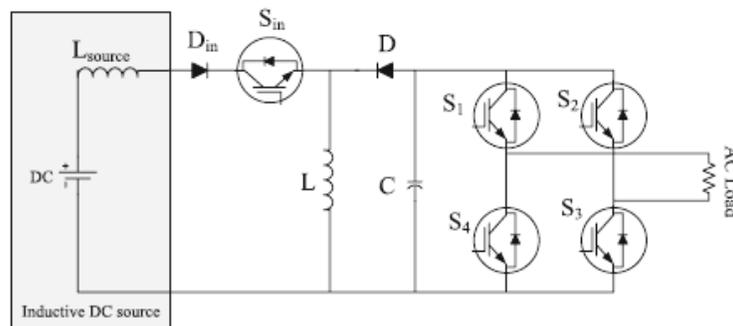
Authors in [17] and [18] suggested a sine-wave modulated buck–boost converter cascaded with a polarity changing inverter. Simulation results demonstrate that this topology works exceptionally well, producing an ac sine-wave output, which depends upon the reference sine-wave amplitude. Furthermore, switching losses are practically limited to the single semiconducting switch of the buck–boost converter. Additionally, there is no need for a big and expensive stabilizing electrolytic capacitor at the dc bus. Low inertia is required at the common bus of the two converters, so thin-film, low capacity, and long life capacitor is used, instead. However, there are drawbacks for this topology and the previously presented modulation methods, which are not mentioned in [17] or [18]. First, voltage is usually not zero when the inverter swaps output polarity. Low-order odd harmonics are created and THD is compromised. Second, when the dc source is inductive, e.g., a wind turbine generator, the output of the sine-wave modulated buck–boost converter is not an ideal rectified sine anymore. In this case, the waveform peaks are shifted to higher angles than  $90^\circ$ ; a distortion which is visualized as a significant third harmonic in the Fourier analysis.

In this study, we present a simple, but effective, improvement of the sine-wave modulation of the buck–boost converter, so that the output capacitor's remaining voltage is minimized when the inverter swaps output polarity. Additionally, a low-order harmonic elimination method, superimposed on the buck–boost modulation, is presented. The initial aim of the method was to remedy the output distortion due to the inductive power source, but in practice it improves the harmonic content of the output whether the reason of the distortion is the source, the load, the synchronized grid, or a combination of the aforementioned elements. Similarly, to the methods reviewed in [13], specific harmonics are injected in order to improve the harmonic content of the output. However, these methods share the feature that the injected harmonic amplitudes are pre calculated, according to the expected harmonic distortion created by the PWM itself [19], [20]. In our approach, output harmonic content is continuously monitored and mitigated. Computational power is consumed mostly for the measurement of the angle and magnitude of output harmonics (a pre requirement of online harmonic mitigation control), rather than the creation of the cancellation harmonics. A prototype converter was created with a single DSP controlling both the buck–boost converter and the inverter.

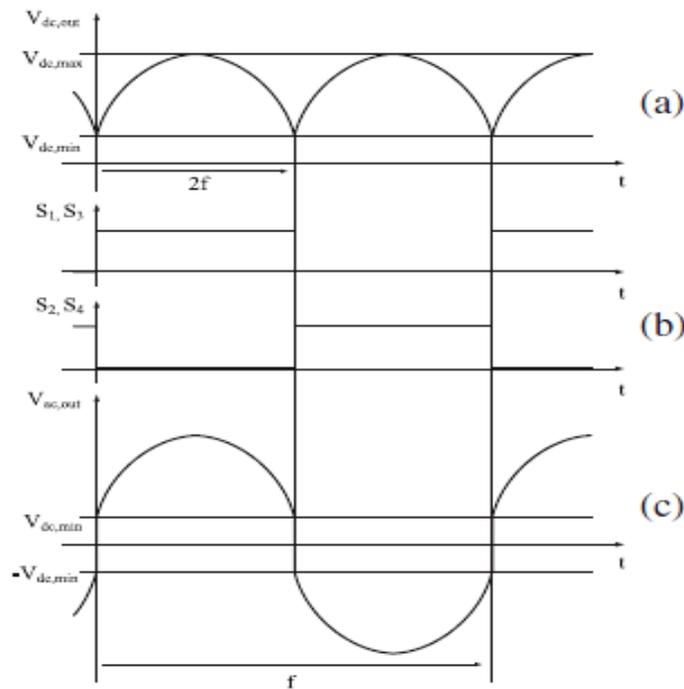
The proposed HA converter that combines an inductor, two voltage sources which shares the ground terminal, and six switches: switches  $S_1$ ,  $S_3$ ,  $S_4$ , and  $S_6$  with inductor  $L$  consists of an H-bridge, and  $S_5$  and  $S_2$  are added to each terminal of  $L$ . The HA converter is a flexible and expandable topology that is applicable to the various applications such as ac–dc, dc–dc, and dc–ac conversions.[4,5]

## 2. PROPOSED SYSTEM

The dc–ac conversion circuit utilized in this study is the one suggested in [17]. It is a buck–boost converter coupled with a voltage polarity changing inverter; see Fig. 1. The buck–boost converter continuously produces a rectified sine voltage  $V_{dc}$ , out [see Fig. 2(a)] with double the frequency  $f$  of the required output [see Fig. 2(c)]. A full bridge inverter is synchronized with the buck–boost converter [see Fig. 2(b)], so that it swaps its polarity. Producing a sine-wave output voltage. The full-bridge inverter swaps polarity when the dc voltage is ideally zero. In reality, though, the dc voltage can reach zero only under a specific heavy load or/and low-frequency conditions at the ac side. This is caused by two factors.

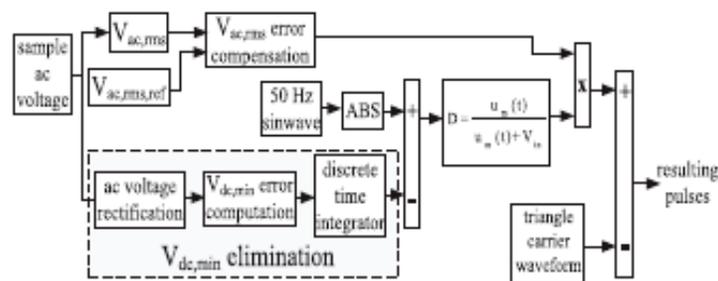


**Fig-1:** Converter topology connected to DC nature of the source



**Fig-2:** The operational characteristics of converter topology: a) DC input voltage, b) Output of boost converter, c) Switching pulses to S1, S3, d) Switching pulses to S2, S4, e) Output voltage of inverter

First, the buck boost converter enters non continuous conduction mode during time periods that the alternating load current drops below a threshold defined by the inductor size and switching frequency. In discontinuous mode, the output voltage of the dc converter is not given by (1), but it is a function of load, so it cannot be pre calculated without an additional current sensor. Fig. 3 shows the ac voltage  $V_{ac, out}$  and inductor  $L$  current ( $i_{choke}$ ) of our prototype under two different loads. We present it as an example of how  $V_{dc, min}$  is affected by load when current takes zero instant values (i.e., dc converter enters discontinuous mode). A second factor is the remaining voltage of the dc-link capacitor. In simple terms, the greater the output capacity, the smoother the output voltage. Therefore, minimum dc voltage depends on the capacitor value. However, too low capacitance would lead to the high voltage ripple due to switching at dc output and voltage surges on semiconductor elements, etc. Therefore, generally polarity swapping takes place when dc voltage drops to a minimum ( $V_{dc, min}$ ) and not zero. In practice, this is achieved by continuously monitoring  $V_{dc, out}$  using a voltage transducer and identifying its minimum value per period. The above operating principle is depicted in Fig. 2(c).



**Fig-3:** Block diagram of the dc elimination.

### 2.1 Reducing the Remaining DC Voltage of the output Capacitor of the DC Converter

Harmonic content is improved, if the remaining dc voltage at the output of the dc converter is reduced. The idea is based on the assumption that the output of the buck–boost converter consists of a constant component  $V_{dc, min}$  and

a rectified sine component [see Fig. 4 (a)]. The reduction of  $V_{dc, min}$  is accomplished via the method defined in the block entitled “ $V_{dc, min}$  elimination” in Fig. 4 and also in Fig. 3. First, the sampled ac output voltage is rectified and  $V_{dc, min}$  is measured.

Then, a dc component is subtracted [see Fig. 5(a)], so that a type of “dead-band” is created at the modulation waveform ( $u_m(t) = \sin 1 - dc$ ) that is used for the calculation of the duty cycle of the buck–boost converter [see Fig. 4(b)]. Then, the modulation waveform  $D$  is calculated [see Figs. 3 and 4(b)] and compared with the carrier triangle waveform [see Fig. 4 (c)], so that the length and frequency of the pulses of the buck–boost converter.

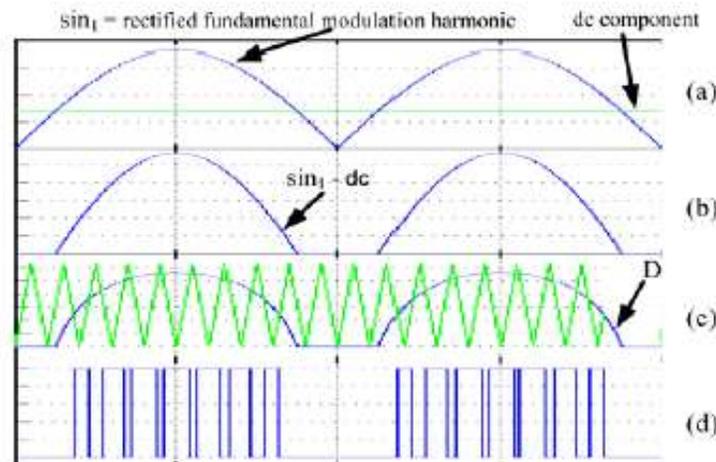


Fig-4: Creation of the pulses for  $V_{dc, min}$  elimination.

### 2.2 Suggested Modulation Technique of the DC Converter with Harmonic Injection and DC Step Elimination:

In order to tackle the low-order harmonics appearing in the output of the converter, we suggest a cancellation scheme based on the injection of mirror harmonics during the construction of the of the output is calculated with a Fourier analysis. Then, we add low-order harmonics (e.g., third, fifth) to the modulation sine wave at the fundamental frequency equal in magnitude, but with a  $180^\circ$  phase difference to the output harmonics to be eliminated. The algorithm implementing the cancellation is presented in Fig. 5 modulation signal of the dc converter. The harmonic content

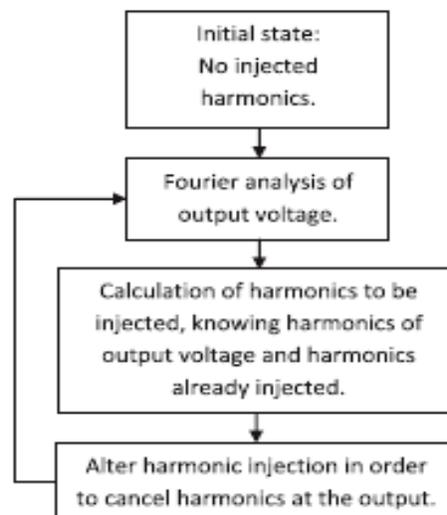


Fig-5: Suggested harmonic cancellation algorithm.

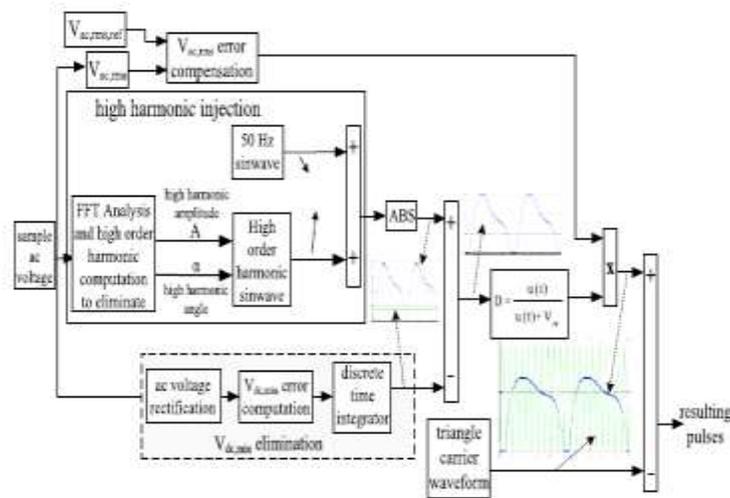


Fig-6: Block diagram of the proposed modulation methods

A dc source supplying three voltage levels (30.9, 61.8, and 90 V) was used. The different voltage levels simulate the operation of renewable energy sources (e.g., wind turbines, solar arrays), which usually supply a varying level of the dc voltage. The load was chosen to be purely resistive, so that the THD improvement is justified only by the proposed method and not by some current smoothing effect of the load. The buck–boost converter operates at a switching frequency of 20 kHz and the inverter changes polarity at 50 Hz. The prototype was also tested under different output target rms voltages. First, we apply the method for the reduction of  $V_{dc, min}$  of the dc converter. Fig. 10(a) presents the output voltage of the prototype for  $V_{source} = 61.8$  V and  $V_{ac, out, rms} = 74$  V without  $V_{dc, min}$  elimination (modulation with pure sine wave).  $V_{dc, min}$  is reduced from 12 to 4 V when the method is applied.

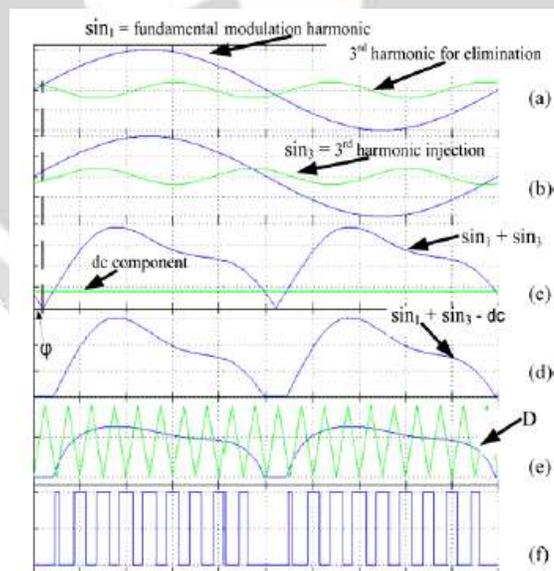
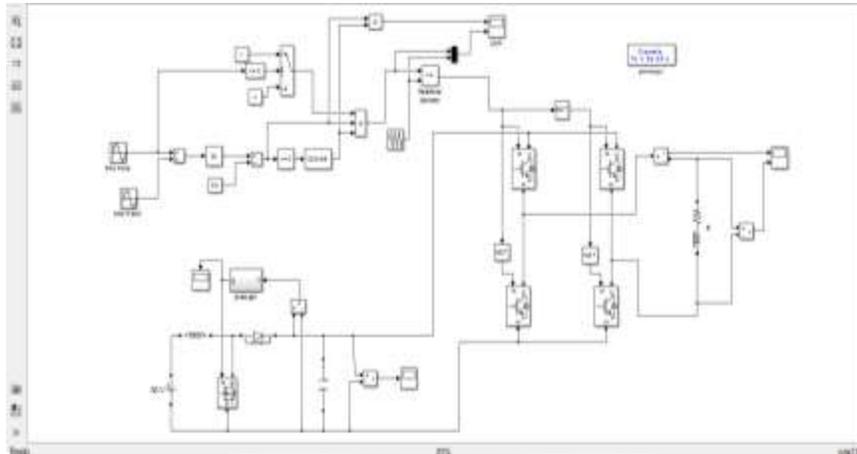


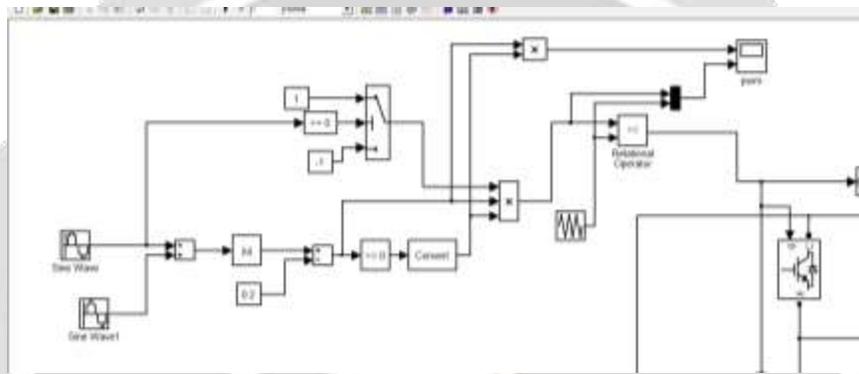
Fig.-7: Creation of modulation pulses for the dc converter.

### 3. SIMULATION RESULTS

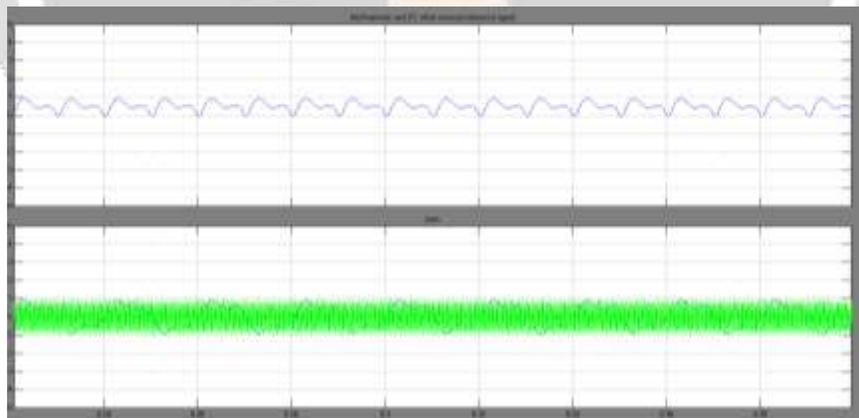
The simulation of the proposed system using MATLAB has shown in figures from 8 to 11. The suppression of harmonics especially even harmonic has done using proposed method



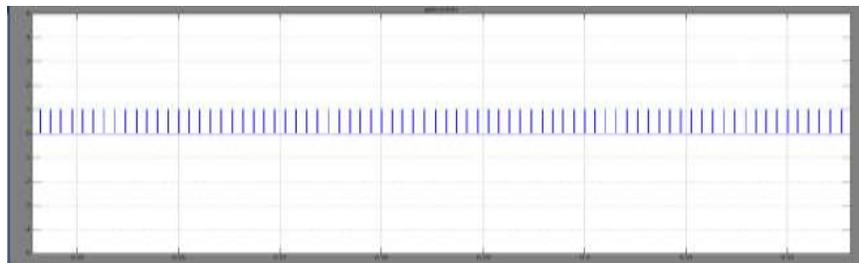
**Fig-8:** Simulation of the proposed topology



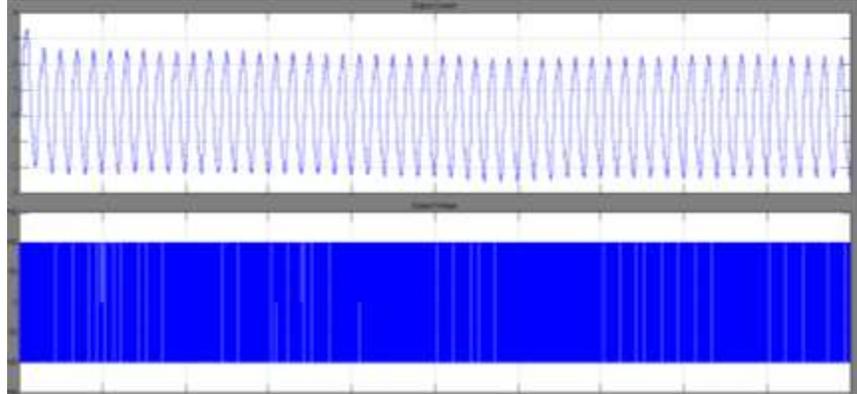
**Fig-9:** Proposed harmonic elimination controller



**Fig-10:** Reference Harmonic eliminated sine versus carrier



**Fig-11** PWM pulses for Inverter



**Fig-12:** Output current and voltage

The figure 12 clearly depicts the quality of output/grid injected current as sinusoidal.

#### 4. CONCLUSION

We have presented a modulation method for the reduction of harmonics at the connection point of a dc–ac converter. The converter is a buck–boost dc converter in series with a changing polarity inverter. Specific harmonics can be canceled, if this is required by the application. The simulation results demonstrate the improvement of THD, through the cancellation of low-order harmonics, so that the output voltage complies with the limit imposed by the standards, without the use of a filter. The method makes no distinction whether harmonics are created from the converter itself or they are supplied by other sources to the connection point. Therefore, further research could lead to the creation of a grid-connected dc–ac converter with harmonic cancellation capabilities.

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